SYNOPSIS OF RESEARCH PROJECT

1.	**Name of Student**	:	PIYUSH PATEL
2.	**Registration No**	:	1010125046
3.	**Faculty**	:	Agriculture
4.	**Name of Degree submitted for**	:	Ph.D. (Agri.)
5.	**Major Subject**	:	Agronomy
6.	**Minor Subject**	:	Soil Science
7.	**Name of Major Guide**	:	Dr. G. S. Vala Research Scientist Agriculture Research Station J.A.U., Mahuva, Bhavnagar
8.	**Title of Research Project**	:	**EFFECTS OF IRRIGATION REGIMES AND BIO STIMULANTS ON LATE SOWN WHEAT UNDER TERMINAL HEAT STRESS**

9. Introduction

Wheat (*Triticum aestivum* L.) is taken into consideration as the King of Cereals. It belongs to the family Poaceae, and it has 21 pairs of chromosomes. It is one of the world's most widely consumed cereal grains, occupying a central position in the global food security framework, and India is the second-largest producer of wheat globally, after China. After rice, wheat is the next most important food crop in India. It generates for almost one-third of all food grain production. It provides approximately 20% of the world's dietary energy supply and is a major source of carbohydrates, protein, and essential nutrients and contains vitamins and minerals such as vitamin B, iron, and magnesium (Shewry and Hey 2015). However, to meet the projected wheat demand of 140 mt in the country by 2050, research must continue at the current pace, with future research efforts focused on evolving new and innovative production technologies that can fit into the framework of changing wheat production scenarios (Ghosh *et al*., 2023). In 2023–2024, it was grown on 32.76 million hectares in India, yielding 117.51 million tonnes and a productivity of approximately 35.87 t/ha. (Anonymous 2024).

Biostimulants are substances or microorganisms applied to plants, seeds, or soil that enhance natural processes to improve nutrient uptake, nutrient efficiency, crop quality, productivity, and enhance resilience against abiotic stressors such heat, cold, salinity, and

drought. Unlike fertilisers, they do not directly provide nutrients but improve the plant's ability to use nutrients already present in the soil. Most of these biostimulant application methods have shown a beneficial effect on crop yield by (i) stimulating germination, vegetative and reproductive growth, especially the root development (density and depth), and (ii) improving plant resilience to biotic/abiotic stress after induction of plant biological activity (Ganugi *et al*., 2019; Rouphael *et al*., 2017). In fact, biostimulants enhance the crop's physiological and biochemical processes by regulating hormone balance, enhancing photosynthetic activity, nutrient uptake, and nutritional efficiency (Fiorentino *et al*., 2018; Woo *et al*., 2014).

Foliar application of biostimulants has proven particularly effective, as it delivers nutrients directly to leaves, ensuring rapid absorption and minimising dependence on soil conditions (Delfine *et al*., 2005; Yadav *et al*., 2021). Biostimulants provide a sustainable solution to problems in wheat cultivation, like limited nutrient availability and environmental stresses, by increasing crop performance and nutrient efficiency (Yaseen *et al*., 2011).

Seaweed-based biostimulants are extracted and manufactured from various genera of marine algae such as *Kappaphycus, Sargassum*, *Ascophyllum, Laminaria, etc*. The natural growth regulators present in the SWE are recognised for their beneficial effects in plant metabolism and growth (Latif *et al*., 2018; Sani and Yong 2022). These natural growth regulators enhance the plant's resilience to abiotic stressors, such as heat stress and drought stress. *etc*. (Alasvandyari *et al*., 2024; Herrera *et al*., 2024). Foliar seaweed extract application alters the leaf osmotic potentials and, in turn, controls stomatal opening, resulting in greater plant growth and productivity under water-stressed situations (Vafa *et al*., 2024). Seaweed contains plant growth hormones, trace elements, and plant growth regulators (auxin, cytokinin and gibberellin) that help in boosting crop productivity by promoting the plant metabolic process (Pal *et al*., 2015).

Thiourea [$CS(NH_2)_2$] is a sulfur-containing organic compound belonging to the group of thiol-based plant growth regulators/osmoprotectants. Its sulfhydryl (-SH) functional group is essential in regulating biochemical and plant physiological processes, particularly in stressful situations. Thiourea is utilised as a foliar stress ameliorant in agricultural science to improve growth, photosynthesis, and production, especially under abiotic stresses including salinity, heat, and drought. Thiourea (TU), a significant synthetic PGR that contains 36% nitrogen and 42% sulphur, has drawn a lot of interest due to its function in plant stress tolerance. (Wahid *et al*., 2017). When thiourea is applied as a foliar spray, it

is absorbed through leaf surfaces and enters plant metabolic pathways, triggering several physiological and biochemical responses. It enhances the quantity of chlorophyll and protects chloroplast structure, thereby improving photosynthetic rate and CO_2 fixation, it also enhances mineral nutrition and its metabolism in plants, thereby improving grain nutritional quality, ultimately sustaining growth even under stress (Perveen *et al*., 2016). It enhances enzymes like Superoxide dismutase (SOD), Catalase (CAT), Peroxidase (POD), and reduces reactive oxygen species (ROS) damage caused by heat stress (Srivastava *et al*., 2011).

Putrescine, a low molecular weight aliphatic polyamine (1,4-diaminobutane), is a member of the polyamine (PA) group, which also includes spermidine and spermine. which are positively charged compounds involved in stress tolerance mechanisms, cell division and elongation, and membrane stabilisation. Polyamines like putrescine act as plant growth regulators and osmoprotectants, especially under abiotic stresses such as heat, drought, and salinity (Sharma *et al*., 2024). When it is applied as a foliar spray in wheat, putrescine has various yield-related (growth and yield improvement), physiological benefits (chlorophyll content, Relative water content, membrane stability index) and biochemical changes (increased proline accumulation) (Singh *et al*., 2025; Hassan and Bano, 2016). Putrescine lowers the effects of heat stress in a number of ways: Under heat stress, the antioxidant defense system, cellular structure protection, photosynthesis maintenance, osmotic adjustment, and yield stability (Singh *et al*., 2025).

Glycine betaine (GB) is a quaternary ammonium compound (N, N, N-trimethylglycine) that acts as an osmoprotectant in plants. Under heat stress, it protects photosystem II, maintains chlorophyll and stomatal conductance, reduces oxidative damage, and enhances grain filling, thereby increasing productivity (Bharti *et al*., 2018). It is regarded as one of the best exogenous defenses against abiotic stresses like salinity, heat, and drought (Ahmed *et al*., 2019). When it is applied as a foliar spray in wheat, it improves growth, yield, photosynthetic efficiency, biochemical effects and improves water use efficiency. (Rossi and Huang 2025; Ahmed *et al*., 2019). Glycine betaine mitigates these effects through the following mechanisms: osmotic adjustment and cell protection, hormonal and molecular regulation, maintenance of photosynthesis, and protection of photosynthetic machinery (wang *et al*., 2014).

The tremendously increasing world population demands a very significant increase in wheat production to feed them. Globally, the rise in temperature during the wheat-growing season is observed, likely due to changes in environmental (climatic) conditions that affect

crop growth and productivity. It came out that a temperature increase throughout the anthesis to maturity phase substantially lowered grain production. However, estimated the loss in grain production to the tune of about 5% (Lobell *et al*., 2011; Liu *et al*., 2016). Wheat is exposed to extreme heat in India because of shorter winters, delayed sowing, and rising grain- filling temperatures, especially across the Indo- Gangetic plains. This makes it hard to control the temperature and severely limits yield and productivity. Adaptation methods are necessary as 70–80% of farmers are small to medium-sized, overseeing 2-3 hectares of land. So, farmers are finding it more difficult to cultivate wheat due to heat stress and rising temperatures. Terminal heat stress is a major cause, so terminal heat control is needed (Bhatt *et al*., 2025; Das *et al*., 2025). One of the biggest global problems is the loss of grain quality and production carried on by heat stress, which is most likely a result of global warming (Schmidhuber *et al*., 2007).

When high temperatures affect wheat, effective terminal heat management becomes crucial for its growth and production. During flowering, it causes underdeveloped embryos, pollen, and other sterility, reducing grain production. Heat stress decreases grain filling during grain-filling, lowering grain weight and yield (Zhao *et al*., 2022). This weather is indicated by March and April temperature increases. Wheat is either milking or grain hardening. Wheat requires 20– 25 degrees Celsius for grain filling. This disrupts grain formation, thins the head grain, and lowers yield if the temperature persists above this point. Terminal heat stress lowers the wheat yield by shrinking cells, lowering internode width, biomass, and productive tiller survival, while accelerating senescence and increasing unproductive tillers (Kaur *et al*., 2017).

10. Practical Utility of the Research Project

The research on the effects of irrigation regimes and bio-stimulants on late-sown wheat under terminal heat stress has practical utility in improving crop productivity, climate resilience and resource use efficiency. During the grain filling stage, late-sown wheat typically suffers high temperatures, leading to decreased yield and poor quality of grain. Maintaining soil moisture, lowering canopy temperature, and promoting plant development under stressful circumstances are all made possible by effective irrigation management., while bio-stimulants such as thiourea, putrescine, glycine betaine, and seaweed extracts enhance physiological processes like nutrient uptake, photosynthesis, and antioxidant activity. Together, these practices improve the plant's ability to tolerate heat stress by maintaining water balance and protecting cellular functions. Furthermore, the combined use of irrigation and bio-stimulants can increase water use efficiency, improve yield, reduce

input costs and improve grain quality, ultimately leading to better economic returns for farmers. Therefore, this approach serves as an effective, practical strategy for sustaining wheat production under changing climatic conditions.

Too far, very little systemic study has been conducted to assess the effects of irrigation regimes and bio-stimulants on late-sown wheat under terminal heat stress. In accordance with the information mentioned above, field experiment will be conducted during the Rabi season of 2026–2027 at the instructional farm, Department of Agronomy, College of Agriculture, JAU, Junagadh–362001.

11. Objectives

1. To assess the effect of irrigation regimes on growth, yield and quality of wheat under terminal heat stress.
2. To evaluate the effect of biostimulants on growth, yield and quality of wheat in mitigating terminal heat stress.
3. To assess the interaction effect of irrigation regimes and biostimulants on growth and productivity of wheat, if any.
4. To work out the economic feasibility of different treatments.

12. Review of Literature

12.1 Effect of irrigation regimes on growth, yield and quality in wheat under terminal heat stress

Nand *et al*. (2014) observed that the application of five irrigations at key growth stages (CRI, maximum tillering, late jointing, flowering, and milking) along with full recommended NPK (120:60:40 kg/ha) significantly enhanced crop growth in terms of plant height, number of shoots per m², leaf area index, and dry matter production. The treatment also recorded significantly higher yield attributes and grain yield (43.6 q/ha) over the 0.8 IW/CPE ratio with three irrigations, and remained at par with the 1.0 IW/CPE ratio

Nayak *et al*. (2015) performed a field study in Anand, Gujarat. and assessed growth characteristics such as height of a plant (cm), ear length (cm), test weight (g), straw and grain yield (4538 and 4380 kg/ha, respectively), were much higher under the treatment having irrigation at 6 stages, such as crown root initiation, tillering, booting, flowering, milking, and dough stage. However, irrigation applied at CRI, tillering, booting, flowering, milking, and dough stages under a 0.8 IW:CPE ratio resulted in more overall tillers per plant, number of spikes/ears, grain weight per ear (cm), and harvest index (%).

Gupta *et al*. (2016) concluded from a study at Faizabad, U.P., with different irrigation scheduling and observed that all growth parameters, such as height of the plant,

and dry matter accumulation (g/m^2), number of shoots/m^2,yield attributes, grain yield (33.8 q/ha), straw yield (43.3 q/ha) and harvest index (43.9 %), were considerably higher with irrigation applied at 1.2 IW/CPE, which was comparable to the treatment with five irrigations at CRI, tillering, late jointing, blooming, and milking stages, as well as the treatment with irrigation at 1.0 IW/CPE. However, the treatment having 2 irrigations each at the CRI and milking stage showed the highest water use efficiency (161.11 kg/ha/cm).

Meena *et al*. (2017) performed a field study in Kota to evaluate irrigation at different crop stages and resulted that applying irrigation at the late milk stage was comparable to the early soft dough stage with regarding the height of the plant (cm), dry matter accumulation (g/m^2), spike/m^2, grains/spike, grain weight/spike (g), leaf area index, grain yield (5.3 t/ha), straw yield (7.0 t/ha), and water use efficiency (152.93 kg/ha/cm).

Kaur *et al*. (2018) resulted from an experiment that maximum parameters of growth viz. height of the plant (cm), leaf area index, no. of tillers/m^2, dry matter accumulation (g/m^2), yield attributes viz. no. of grains/spike, spike length (cm), test weight (g), grain yield (60.26 q/ha), straw yield (75.45 q/ha), biological yield (135.71 q/ha), harvest Index (44.68 %) were at their highest when the treatment was applied having mulch wheat (5 t/ha) + irrigation (at CRI, MT and F stage over the remaining treatments (at CRI, MT, J and M stage) that were equivalent to irrigation.

Singh *et al*. (2018) investigated a field trial at Faizabad, U.P., and observed that applying four irrigations resulted in superior growth and yield parameters. It recorded the highest plant height (74.63 cm), number of tillers (81.33 m²), dry matter accumulation at harvest (93.16 g/m²), and leaf area index (3.85 at 90 DAS). Additionally, this treatment produced a higher yield of straw (32.37 q/ha), yield of a grain (23.12 q/ha) and harvest index (41.99) compared to treatments receiving one or two irrigations

Verma *et al*. (2018) investigated that pooled data from a field research conducted in Jobner, Rajasthan, showed that irrigation applied at a ratio of 0.9 IW/CPE produced the highest growth index values (matter accumulation per metre row length, leaf area index, leaf area duration, crop growth rate, relative growth rate and net assimilation rate) and yield [grain (4.45 t/ha), straw (6.34 t/ha), biological (10.80 t/ha) and HI] proved considerably superior to the other treatments, with the exception of treatment 0.8 IW/CPE ratio through the vegetative phase + 1.0 IW/CPE ratio through the reproductive phase. However, the treatment that attained the maximum water-use efficiency (WUE) and surpassed the other treatments was 0.8 IW: CPE ratio during the vegetative phase + 1.0 IW: CPE ratio through the reproductive phase.

Abhineet *et al*. (2019) investigated a research trial at Ayodhya and observed that the application of two irrigations, first at the CRI stage and second at the boot leaf stage, resulted in the highest values for various growth and yield attributes. These included effective tillers (314.56/m²), ear length (8.97 cm), grains per ear (44.16), grain weight per ear (1.36 g), 1000-grain weight (38.24 g), biological yield (81.23 q/ha), grain yield (33.45 q/ha), and straw yield (47.78 q/ha). This treatment was found to be significantly higher than the other irrigation levels.

Alam *et al*. (2019) performed a field study at Ranchi, Jharkhand's Birsa Agricultural University. They evaluated three irrigation levels: IR_1 (CRI stage), IR_2 (CRI, tillering, and boot leaf stages), and IR_3 (CRI, tillering, jointing, boot leaf, and milk stages). Among these, five irrigations (IR_3) produced superior results and significantly influenced most yield parameters. A higher number of irrigations increased effective tillers, spike length (12.7 cm), fertile spikelets/spike (46.27), grains per spike (41.42), and 1000-grain weight (41.31 g), ultimately resulting in a 20.89% increase in grain and straw yield (37.97 and 55.04 q/ha, respectively).

Dar *et al*. (2019) concluded from their field study at Ludhiana, Punjab, that maintaining irrigation at 15% depletion level (with 10 irrigations in total) proved most effective. It recorded superior growth and yield parameters, including plant height, tillers per m², leaf area index, ear length and weight, dry matter accumulation, grain yield (5.37 t/ha), biological yield (12.34 t/ha), and harvest index (43.4%) compared to other treatments.

Barla *et al*. (2020) observed that the application of four irrigations resulted in the highest plant height, spike length, total and effective tillers per m², and 1000 grain weight compared to three irrigation levels. However, grain yield (4490 kg/ha) and straw yield (6481 kg/ha) recorded under three irrigations were comparable to those obtained with four irrigations.

Kanwal *et al*. (2020) investigated out an experiment in RCBD in which wheat was tested under various numbers of irrigations levels and resulted that 4 number of irrigations had significantly highest, height of plant, length of spike (cm), no. of spikelets/spike, highest leaf area index, biological yield, grain yield (5.41 t/ha), straw yield of (2.1 t/ha) and harvest index (37.6 %) significantly. While the days to booting, tillers/m^2, number of grains/spike, grain weight/spike, and weight of 1000 grains had no significant differences.

Pal *et al*. (2020) concluded from the experiment that comprised of five levels of irrigation schedule indicated that the growth attributes viz., number of shoots, plant height, dry matter accumulation and yield attributing characters viz., number of grains/spike,

number of spike/m^2, length of spike, 1000 grain weight, grain and straw yield by crop was significantly in 1.0 IW/CPE ratio and was comparable with 1.2 IW/CPE ratio and significantly higher over at the crown root initiation stage, 0.6 IW/CPE ratio, 0.8 IW/CPE ratio.

Zhao *et al*. (2020) studied with four distinct water stress levels: 30–40% of field water capacity for severe stress, 40–50% for moderate stress, 50–60% for mild stress, and 60–80% for well-watered. Compared with the well-watered group, the mildly stressed group's net photosynthetic rate decreased slightly, leading to increases in dry biomass and 1000-grain weight of 2.07% and 1.95%, respectively. Water use efficiency (WUE) and irrigation water productivity (IWP) values under mild stress (50–60%) were greater than those of well-watered winter wheat. Higher yields and reduced water use were linked to higher WUE and IWP.

Chaudhary *et al*. (2021) concluded from a field study at Sardarkrushinagar, Gujarat and observed that the crop was irrigated at 1.0 IW: CPE, resulted in the highest plant height (cm), effective tillers/m^2, number of grains/ear, grain weight/ear (g), 1000-grains weight (g), grain (3.61 t/ha), straw yield (4.78 t/ha) and harvest index (42.96 %).

Kumar *et al*. (2021) experimented that irrigation scheduling significantly influenced growth parameters and yield attributes of wheat. Among the different treatments, the 1.0 IW/CPE ratio recorded the highest height of plant (92.94 cm), number of tillers (389.24/m^2), dry matter accumulation at harvest (882.50 g/m^2), and leaf area index (4.98 at 90 DAS). This treatment also produced higher grain yield (37.40 q/ha), straw yield (50.86 q/ha), and biological yield (88.25 q/ha) compared to other irrigation schedules.

Alam *et al*. (2022) observed that using CRI + IW/CPE=1.0 for the irrigation schedule has significantly higher growth, yield attributes such as effective tillers/m^2, spike length (cm), test weight (g), grains/spike and yield (grains, straw, biological) and harvest index as in comparison to prior IW/CPE ratios of 0.8 and 1.2.

Lakra *et al*. (2022) concluded from a field study that the application of five irrigations at critical growth stages (CRI, jointing, booting, flowering, and milking) proved most effective in improving crop growth and productivity. It led to maximum plant height at harvest (79.9 cm), dry matter accumulation at harvest (385.1 g/m^2), leaf area index (2.60), and higher growth indices between 40–80 DAS, along with the highest biological yield (6,899 kg/ha) compared to other irrigation regimes.

Patel *et al*. (2022) observed that applying irrigation at four key stages (CRI, maximum tillering, and milking) significantly enhanced crop performance. This treatment

recorded the highest plant height, effective tillers, yield attributes (viz. number of grains/spike, number of spikes/m^2, test weight), crop water use efficiency, and yields, including grain (54.46 q/ha), straw (75.01 q/ha), and biological yield (129.47 q/ha), with a harvest index of 42.06%.

Prajapat *et al*. (2022) experimented in the Rajasthan Agricultural Research Institute, Jobner, Rajasthan and conclude that the treatment having irrigations at 1.2 ETc recorded highest grain and biological yield of wheat (11250 kg/ha and 5136 kg/ha) in pooled analysis, respectively over 0.6 ETc and 0.8 ETc and comparable with irrigations at 1.0 ETc and also recorded higher value of Growing degree days (GDD).

Tripathi *et al*. (2023) investigated an field trial at Ayodhya, and found that four irrigations at CRI, jointing, milking and dough stage has highest plant height (cm), number of tillers/m^2, dry matter accumulation (g/m^2), leaf area index, number of spikes/m^2, spike length (cm), no. of grains/spike, test weight (g), grain yield (34.2 q/ha), straw yield (46.32 q/ha), biological yield (80.52 q/ha), harvest Index (42.45 %) which is comparable with irrigation at 0.6 IW/CPE.

Ankit *et al*. (2024) resulted from an experiment at ICAR-Indian Agricultural Research Institute, New Delhi, which comprised of 3 irrigation scheduling regimes included 50% available soil moisture depletion (ASMD), CWSI, i.e. crop water stress index-based, and Conventional crop growth stage-based. Results showed that 50% DASM (Depletion available soil moisture) based irrigation considerably increased dry matter accumulation (5.65 and 5.44%), root length (15.89 and 44.48%), root weight (11.63 and 12.77%), grain N uptake (20.88 and 14.52%), grain yield (11.28 and 6.30%), straw yield (5.33 and 5.70%), and water productivity (11.37 and 6.19%), compared to conventional crop stage based irrigation.

Kumar *et al*. (2024) demonstrated from the experiment that irrigation with 1.0 IW/CPE possessed the most significant growth characteristics., viz. plant height (cm), number of tillers/m^2, leaf area index and dry matter accumulation (g/m^2) as well as biological (127.18 q/ha), grain yield (50.83 q/ha), and harvest index were (40.11%), which was at par with 0.8 IW/CPE ratio.

Soule *et al*. (2024) studied at Djirataoua in the southern part of Niger republic in split plot design having main plot consisting of three sowing dates and sub plot have three irrigation frequencies (5, 10 and 15 days) in split plot design. The highest plant height (103 cm) was achieved with a 5-day interval of irrigation. Also, the highest yield (5545 kg/ha)

was achieved at a 5-day interval of irrigation. But the weight of 1000 grains were statistically similar (39.12 g, 36.53 g and 33.48 g) for the three irrigation intervals.

Islam *et al*. (2025) studied three wheat varieties and four levels of irrigation, viz., no irrigation (control), one irrigation at the crown root initiation (CRI) stage, two irrigations (CRI and the booting stages), and three irrigations (CRI, booting stage, and heading stage). Regarding irrigation, the best results were achieved with three irrigation applications, resulting in the tallest plants (96.22 cm), the highest total tillers/hill (4.79), 1000-grain weight (55.38 g), effective tillers/hill (4.17), grains/spike (44.36), and yield of grain (4.35 t/ha) and harvest index (41.43%).

Kaur *et al.* (2025) performed an field trial to assess how irrigation scheduling affected agrometeorological indices and found that, in comparison to sub-optimal and rainfed treatments, irrigation at 50% depletion of field capacity significantly increased phenological duration, leaf area index, crop growth rate, and relative water content. The highest grain (5.99 t/ha) and straw yields (7.58 t/ha) were recorded under 50% FC depletion, followed closely by 0.50 plant stress index and 30% field capacity depletion.

Sood *et al*. (2025) resulted from an experiment that yield attributes like number of effective tillers/m^2, number of grains/spike, 1000 grain weight, maximum grain yield (3415 kg/ha) and straw yield (4923 kg/ha), growth attributes like plant height (cm), dry matter accumulation (g/m^2), and harvest index were found to be highest under two irrigation regimes, which was greater than that of the rainfed crop and one irrigation.

12.2 Effect of biostimulants on growth, yield and quality in wheat in mitigating terminal heat stress

Bassiouny *et al*. (2008) resulted from an pot experiment in which foliar application of putrescine (0.0, 0.6, 1.25, 2.5 and 5 mM) at three physiological stages (vegetative, 30 DAS; just before emergence of main spike, 60 DAS and during grain filling, and resulted that foliar application of 2.5 mM of putrescine significantly improved the number of tillers/plant, number of leaves/plant, leaf area/plant, and dry weight of shoots/plant of treated wheat plants over controls. Further, putrescine spray on wheat plants at 30 DAS was most effective as compared with the same treatments applied at 60 DAS.

Gupta and Gupta (2011) performed a field study in Bikaner, Rajasthan, and found that 1 mM putrescine foliar sprays improved plant height, leaf area, grain number, grain weight, grain yield, biological yield, and harvest index over 0.01 and 0.1 mM putrescine treatments. Exogenous application of 1 mM putrescine was found to be the best in most of the observations. Among the modes of applications, two foliar sprays of putrescine at the

time of anthesis and post-anthesis performed best over seed treatment and one foliar spray of putrescine.

Shahbaz *et al.* (2011) investigated a pot experiment and found that the exogenous spray of the three levels 0, 50 and 100 mM of glycine betaine applied under well-watered condition and water-stressed condition (60 per cent field capacity) enhance plant biomass, shoot length, transpiration rate, and root phosphorus and nitrogen levels under stress circumstances to reduce the adverse impacts of drought stress; nevertheless, its impact on leaf area/plant and water usage efficiency was not that great. Foliar application of glycine betaine at a concentration of 50 mM showed the best performance in reducing the adverse effects of drought stress on wheat under water deficit conditions.

Gupta *et al*. (2012) investigated out an field experiment in Jobner Rajasthan to find out the efficacy of putrescine and benzyladenine on photosynthesis and productivity in wheat and revealed that putrescine (0.1mM) application on wheat plants at the time of anthesis enhanced the leaf area (cm^2/plant), plant height (cm/plant), numbers of grains/plant, grain yield, straw and biological yield.

Asthir *et al*. (2013) experimented in Punjab Agricultural University, Ludhiana to evaluate the potential of thiourea in improving the terminal heat resistance in wheat and found that combined treatment of thiourea i.e., seeds treatment (6.6mM) and foliar spray at anthesis stage substantially increased the chlorophyll contents, height of plant (cm), length of peduncle (cm), 1000-grain weight (gm) and peduncle weight.

Hassanein *et al*. (2013) concluded from the experiment that the foliar spraying of putrescine (1.25 mM, 2.5 mM) before exposure to high temperature significantly increased fresh and dry weights and water contents of shoots, as well as height of plant (cm), tillers number/plant, spikes number/plant, 1000 grains weight (g), straw yield/plant (g), harvest index (%) over those of the corresponding plants exposed to high temperature stress alone and in some cases of other biochemical compounds and the untreated plants.

Meena (2015) investigated a field study in Udaipur and noticed that, compared to water spray and 100 ppm putrescine, foliar spray of 100 ppm putrescine significantly increased the yield attributes of wheat, including spikes/ear, grains/ear, ear length, test weight, and grain yield (5736 kg/ha), but it was on par with 50 ppm putrescine.

Ahmed *et al*. (2016) concluded from an experiment that spray of 0.2 mM putrescine gave a positive ameliorative effect mostly at 50% field capacity, where it stimulated the different growth parameter such as shoot length (cm), leaf area (cm^2) fresh and dry weight

(g) of root, shoot and spike photosynthetic pigments, crop yield, protein content of wheat genotype.

Amin *et al*. (2016) experimented in Egypt and found that effect of foliar application of benzoic acid and thiourea alone or in combination used as a treatment but the highest tiller number, spikes/m^2, total plant dry weight/m^2, flag leaf area, blades area/plant and yield attributes such as spike length (cm), number of grains/spike, number of spike/m^2, grain index (g), and grain yield (t/fed), straw yield (t/fed) found in spraying thiourea alone at a rate 1000 mg/L compared to 250 and 500 mg/L.

Gupta *et al.* (2017) conducted an field study that the impact of exogenous glycine betaine application on wheat performance during prolonged drought conditions. In comparison to stressed wheat genotypes under drought stress, foliar application of glycine betaine increased the number of productive tillers/m^2, number of grains per spike, thousand grain weight, biological yield, and grain yield.

Zain *et al*. (2017) concluded from an experiment that the growth characteristics of wheat were significantly enhanced with the foliar application of thiourea at the tillering stage, 300 mg/L. Likely, yield contributing traits, such as number of productive tillers, 1000-grain weight, number of grains per spike and grain yield were considerably improved by the foliar application of 300 mg/L of thiourea at the tillering stage. It was concluded that at the tillering stage, the application of thiourea (at 300 mg/L) was highly effective in improving the growth and yield of late-sown wheat.

Sarita *et al.* (2021) showed that applying 4 millilitres per litre of seaweed extract across the tillering and heading stages produced noticeably greater wheat yields, including biological, grain, and straw yields, and was comparable to applying 2 millilitres per litre of water during this period. Foliar application of seaweed extract at the tillering and heading stages yielded significantly higher gross return and net return (4 ml/litre), while foliar application of seaweed extract at the heading stage yielded the highest B:C ratio (2 ml/litre).

Sher *et al*. (2021), evaluated that spraying thiourea (1000 mg/L) at various crop growth stages markedly enhanced growth attributes such as plant height, leaf number, tiller number, and leaf area during both experimental years. It also produced a maximum 1000-grain weight, biological yield, and grain yield compared to untreated plots.

Choudhary *et al*. (2023) investigated an field study at Anand Agricultural University in Gujarat, it was discovered that spraying of seaweed extract at a rate of 4 ml/litre water during the tillering and heading stage significantly outperformed the other treatments in plant height at harvest (81.45 cm), number of ear heads (301/m^2),

physiological maturity days (116), ear length (8.05 cm), number of grain ears (34.48), test weight (44.67 g), grain yield (3333 kg/ha), and biological yield (7974 kg/ha).

Ibrahim *et al.* (2023) experimented at the Menoufia University, Egypt, to study the effect of surface irrigation systems (basin irrigation, bed irrigation and gated pipes) and foliar application of growth stimulants and resulted that spraying of seaweed extract exhibited highest in all yield and its components (number of spikes/m^2, number of grains/spike, 1000-grain weight, grain yield/feddan and straw and biological yields/feddan) as well as grain quality (protein, wet and dry gluten %) in comparison with other tested growth stimulants especially control.

Wasaya *et al*. (2023) evaluated that applying 1.0 ppm putrescine improved the relative water content (19.76%), specific leaf area (41.47%), and leaf area ratio (35.84%) compared with the control treatment, as well as improved the membrane stability index and relative water content, resulting in enhanced 1000-grain weight and spike weight. A higher grain yield (28.0 g/plant) was also obtained with the foliar application of 1.0 ppm putrescine compared with the control treatments. The findings of this study clearly showed the protective role against terminal drought stress.

Pardhi *et al.* (2024) evaluated from an field trial that glycine betaine100 mM followed by salicylic acid 250ppm foliar application treatments significantly highest in growth parameters viz., plant height (59.14 cm, 86.51 cm and 104.74 cm, respectively), leaf area index (3.20, 3.92 and 4.12, respectively) at 60 DAS, 90 DAS and at harvest, number of tillers/ plant (7.85, 5.85), relative water content (81.03%, 76.78%) at 60 DAS and 90 DAS. Furthermore, it was found that the treatment with foliar spray of glycine betaine 100 mM and salicylic acid 250 ppm had the maximum grain production, straw yield, and biological yield of the wheat variety.

Tanmayi *et al*. (2024) observed that spraying sea weed extract at a rate of two milliliters per liter during the tillering and heading stages had an enormous effect resulted in significantly higher spike number/m^2 (325), grain yield (5901 kg/ha), straw yield (9146 kg/ha) and nutrient uptake (110.5, 15.2 and 119.8 kg/ha N, P and K, respectively).

Singh *et al*. (2025) investigated a field study to test the application of seven synthetic compounds on wheat growth traits under heat stress and found that spraying of 100 ppm salicylic acid at anthesis and grain filling stages caused increases in grain yield (19.5%), followed by a 14% increase with 4 mM putrescine. These yield improvements were attributed to higher grains per spike, more effective tillers, and greater 1000-grain weight, reflecting enhanced sink capacity and grain development under stress.

12.3 To assess the interaction effect of irrigation regimes and biostimulants on growth and productivity of wheat `

Magda *et al*. (2014) resulted from an experiment in Egypt and concluded that foliar application of 100 mg/l putrescine and normal irrigation in barley has tallest plant height (136.20 cm), number of tillers/ plant (6.75), spikes dry weight (49.96 g/plant), grain yield (2.97 ton/fed), straw yield (3.70 ton/fed), biological yield (6.67 ton/fed) over 50, 75 mg/l of putrescine.

Wakchaure *et al*. (2016) evaluated from an experiment in Pune and noticed that the treatment containing thiourea and 1.0 IW/CPE had the highest effective tillers/m^2, plant height (cm), spike length (cm), 1000-grain weight (g), biomass production (Mg/ha), and harvest index. Thus, when combined with plant bio-regulators like thiourea and salicylic acid, the effect of deficit irrigation could be significantly improved in terms of grain yield and water productivity.

Karimi Z. (2016) performed out an study in Iran and concluded that normal irrigation with spraying of putrescine 150 ppm significantly increased ear length (cm), 1000 grain weight, no. of grains/ear, grain yield (6582 kg/ha), biological yield (15234 kg/ha) and harvest index (43.24), protein percent and E.C of wheat leaf.

Ahmed *et al*. (2019) demonstrated in a field investigation that the maximum spike length (cm), spikelet number/spike, grain number/spike, 1000-grain weight (g), grain yield (kg/ha), and above-ground biomass (g/plant) were found in conventional irrigation with glycine betaine compared to the remaining treatments in both years.

Hussein *et al*. (2023) investigated a study in Egypt that treatment involving putrescine (1 mM) with control irrigation was most effective in enhancing growth and yield parameters. It achieved the highest values for plant height, leaf number, tiller count, flag leaf area, shoot and root fresh and dry weights, spike length, spike weight, and grain weight per spike among all treatments.

Altuhaish A. A. (2024), evaluated from an research trial that concentration of 1.25 mM putrescine markedly improved plant height, flag leaf area, and total dry biomass over the control. No significant variation in plant height was observed among drought-stressed plants without putrescine, but its application influenced plant height differently under contrasting moisture conditions.

Firdous H. (2025) investigated out an experiment in China on the effect of thiourea and irrigation regimes on yield and its components in wheat and observed that the treatment

having 100% field capacity with 6.5 mM thiourea has the highest spikes/plant, grains/spike, 1000-grain weight (g), grain yield/plant (g) compared to the remaining treatments.

12.4 To work out the economic feasibility of different treatments.

Gupta and Gupta (2011) resulted from a field trial at Bikaner, Rajasthan and showed that in non-water stress conditions, a 1 mM foliar spray of putrescine had the highest gross returns, net returns, cost of cultivation, and B:C ratio.

Nand *et al*. (2014) evaluated from an experiment and found that five irrigations at crown root initiation, maximum tillering, late jointing, flowering, and milking stage along with 100% NPK through chemical fertilizers (120:60:40 kg/ha), followed by irrigation at 0.8 IW/CPE ratio along with 100% NPK through chemical fertilizers (120:60:40/ha), produced the highest cultivation cost (Rs 25,550/ha), gross income (Rs 58,950/ha), net income (Rs 33,400/ha), and benefit: cost ratio (1.30).

Meena *et al*. (2017) investigated out an field study at Kota using irrigation at various crop stages and found that, when compared to early milk, late soft dough stage, and control, irrigation at the late milk stage produced the highest net return (Rs. 86.5 thousand/ha) and B:C ratio (4.27), but it was on par with early soft dough stage.

Kaur *et al*. (2018) experimented in Punjab and revealed that the maximum net return of Rs. 86320/ha and the benefit: cost ratio of 1.75 is found with treatment having mulch wheat (5 t/ha) + irrigation (at crown root initiation, maximum tillering and flowering) over the remaining treatments.

Verma *et al*. (2018) experimented on loamy sand soil in Jobner, Rajasthan and evaluated that highest net return (Rs. 54,883/ha) found in treatment having irrigation scheduling at 0.9 IW/ CPE ratio and lowest net return (Rs. 44,071/ha) was found in 0.6 IW/CPE ratio at vegetative phase + 0.8 IW/CPE ratio at reproductive phase.

Kanwal *et al*. (2020) experimented in RCBD and concluded that four irrigation levels had a potentially high yield, performance and were economically more beneficial than the rest of the treatments, in which the highest net return was found Rs. 49694. After that, three irrigation levels had a high return of Rs. 28000.

Barla *et al*. (2020) concluded from an experiment conducted in Ranchi, Jharkhand, with 3 irrigation levels that the highest net return (Rs. 51919) and B:C (2.09) were achieved with 3 irrigation level, compared with the minimum recorded under two irrigations, i.e., Rs. 44959 and 1.86, respectively.

Pal *et al*. (2020) concluded from an field study at Ayodhya (U.P.) that comprised of five levels of irrigation schedule, indicating that the gross return (Rs 86364/ha), net

return (Rs. 55821/ha) and 1.82 B: C ratio were found to be highest in 1.0 IW/CPE ratio moisture regimes than the remaining treatments.

Chaudhary *et al*. (2021) investigated an experiment at Sardarkrushinagar Dantiwada Agricultural University (SDAU), Gujarat and showed that irrigation at a ratio of 1.0 IW/CPE produced significantly better gross and net returns of Rs. 66188/ha and Rs. 34790/ha, respectively, and B:C 2.11, followed by 0.6 IW/CPE.

Sarita *et al.* (2021) concluded from an experiment in Bhagalpur, Bihar, and found that applying seaweed extract 4 milliliters per litre at the tillering and heading stages produced a significantly higher gross return (Rs. 119502.69/ha), net return (Rs. 82957.15/ha), and maximum B:C ratio (2.38%) when applying seaweed extract 2 milliliters per liter at the heading stage.

Patel *et al*. (2022) evaluated from an experiment in Kanpur and observed that four irrigation levels at crown root initiation, maximum tillering, late jointing, and milking stage produced the highest net return (Rs. 70379/ha) and B:C (1.32) compared to the other irrigation levels.

Tanmayi *et al*. (2024) performed a research trial and reported that the maximum gross returns (Rs. 112113/ha), net returns (Rs. 67188/ha), and B:C (2.50) were obtained by foliar treatment of seaweed extract, which was comparable to spraying 4 ml/litre of seaweed extract during the tillering and heading stages.

Sood *et al*. (2025) experimented in Palampur and concluded that the highest B:C ratio was recorded under two irrigations (2.64), followed by one irrigation (2.43), while the lowest B:C ratio was observed under rainfed conditions (2.13)

Giramkar *et al*. (2025) experimented at Rahuri, Maharashtra and resulted that treatment, combining 100% RD of NPK and two foliar sprays of biostimulant powder (3 g L^{-1}) gives the highest gross monetary returns (₹1,35,929 ha^{-1}), net monetary returns (₹80,831 ha^{-1}), and B:C ratio (2.47).

13. Materials and Methods

Table 1. Details regarding the crop to be sown

1.	**Crop and Variety**	Wheat and GW 513
2.	**Spacing**	18 cm
3.	**Seed rate**	150 kg/ha
4.	**Plot size**	Gross: 5m × 3m Net: 4m × 2.5m
5.	**Recommended dose of fertiliser**	80-40-0 kg N, P_2O_5 and K_2O/ha

13.1	**Location**	Instructional Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh
13.2	**Year and season of experiment**	2026-27 and 2027-28, *Rabi*
13.3	**Experimental design**	Split plot design

13.4 Treatment details

A. Main plot (Irrigation regimes)

I_1: Number of irrigations – 10 (9+ 1 common after sowing)

I_2: Number of irrigations – 7 (6 + 1 common after sowing)

I_3: Number of irrigations – 5 (4 + 1 common after sowing)

B. Sub plot (Different Biostimulants)

B_0 – control (no spray)

B_1 – Seaweed extract (0.3%)

B_2 – Thiourea (20mM) [1522 ppm]

B_3 – Putrescine (1mM) [88 ppm]

B_4 – Glycine betaine (100mM) [11,715 ppm]

Note: Two foliar sprays at booting stage and grain filling stage

Note: The irrigations will be given as per the details given below

I_1: Number of irrigations – 10 (9 + 1 common after sowing)

1. Early vegetative stage
2. Crown root initiation
3. Tillering stage
4. Jointing stage
5. Booting stage
6. Heading stage
7. Flowering (Anthesis) stage
8. Milking stage
9. Dough stage

I_2: Number of irrigations – 7 (6 + 1 common after sowing)

1. Crown root initiation
2. Late tillering stage
3. Booting stage
4. Flowering (Anthesis) stage
5. Milking stage

6. Dough stage

I_3: Number of irrigations – 5 (4 + 1 common after sowing)

1. Crown root initiation
2. Jointing stage
3. Flowering (Anthesis) stage
4. Milking stage

13.5 No. of replications: Three (3)

13.6 Observations to be recorded

13.6.1 Growth Parameters

1. Initial and final plant population
2. Plant height (cm) at harvest
3. Dry matter accumulation (g/plant) at 30, 60 DAS and at harvest
4. Flag leaf area at anthesis and dough stage
5. Leaf area index (LAI) at 30, 60 & 90 DAS.
6. Crop Growth Rate at 0-30 DAS, 30-60 DAS, 60 DAS-harvest
7. Relative Growth Rate at 0-30 DAS, 30-60 DAS, 60 DAS-harvest

13.6.2 Yield attributes and yield

1. No. of effective tillers/m^2
2. Length of spike (cm)
3. No. of grains/spike
4. Grain weight/spike (g)
5. 1000 grain weight (g)

13.6.3 Yield

1. Grain yield (kg/ha)
2. Straw yield (kg/ha)
3. Biological yield (kg/ha)
4. Harvest index (%)

13.6.4 Plant analysis

1. N, P, K content in grain and straw
2. N, P, K uptake (kg/ha) by grain and straw

13.6.5 Biochemical studies

1. Proline content of leaves at 55 and 70 DAS
2. Chlorophyll content of leaves at 55 and 70 DAS
3. Electrical conductivity of leaves at 55 and 70 DAS

4. Relative water content of leaves at 55 and 70 DAS

5. Membrane stability index

6. Protein content (%)

13.6.6 Soil and Water Parameters

1. Water use efficiency (kg/ha/mm)

2. Soil moisture content at 0-20 cm depth before and after each irrigation

3. Available N, P_2O_5 and K_2O at initial and after harvest

13.6.7 Economic evaluation

1. Cost of cultivation (Rs/ha)

2. Gross return (Rs/ha)

3. Net returns (Rs/ha)

4. B: C ratio

13.6.8 Agrometeorological studies

1. Growing degree days (°C·day)

2. Heat use efficiency (kg ha^{-1}/°C day)

Table 2: Details of methods used for estimation of nutrient status in soil

Sr No.	Parameters	Methods	References
1.	Available N in the soil	Alkaline permanganate method	Subbiah and Asija (1956)
2.	Available P_2O_5 in the soil	Olsen's method	Olsen *et al.* (1954)
3.	Available K_2O in the soil	Flame photometric method	Jackson (1974)

14 Statistical analysis

The data will be subjected to statistical analysis by adopting appropriate analysis of variance as described by Gomez and Gomez (1984). Wherever the F values are found significant at 5% level of probability, the critical difference (CD) values will be computed for making comparisons among the treatment means.

15. References

Abhineet, R. K., Singh, S., Nand, V. and Chaudhary, V. (2019). Effect of restricted irrigation levels on yield attributes and yield of various varieties of wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry*, **8**(2): 122-125.

Ahmed, M. M. M. and Sadak, M. S. (2016). Effect of putrescine foliar application on wheat genotypes (*Triticum aestivum* L.) under water stress conditions. *International Journal of Pharmtech Research*, **9**(8): 94-102.

Ahmed, N., Zhang, Y., Li, K., Zhou, Y., Zhang, M. and Li, Z. (2019). Exogenous application of glycine betaine improved water use efficiency in winter wheat (*Triticum aestivum* L.) via modulating photosynthetic efficiency and antioxidative capacity under conventional and limited irrigation conditions. *The Crop Journal*, **7**(5): 635-650.

Alam, M. P., Singh, S. K. and Kumar, K. (2019). Behaviour of different wheat genotypes under various irrigation conditions under eastern region of Jharkhand. *Journal of Pharmacognosy and Phytochemistry,* SP2: 82-84.

Alam, M. S., Naresh, R. K., Vivek, K. S. and Singh, H. L. (2022). Effect of sowing methods and irrigation scheduling on production and productivity of wheat crop. In *Biological Forum–An International Journal*, **14**(2a): 445-452.

Alasvandyari, F., Mahdavi, B. and Rahimi, A. (2024). Alleviating the water deficit stress effect on *Zea mays* L. using an extract of the seaweed *Sargassum boveanum*. *Journal of Applied Phycology*, **36**: 2951–2960.

Altuhaish, A. A. (2024). Enhancing the growth of wheat (*Triticum aestivum* L.) through putrescine application under drought stress conditions. *Academy Journal for Basic and Applied Sciences*, **6**(3).

Amin, A. A., Kader, A. A. A., Abouziena, H. F., El-Awadi, M. and Gharib, F. A. E. (2016). Effects of benzoic acid and thiourea on growth and productivity of wheat (*Triticum aestivum* L.) plants. *International Journal of Scientific Research,* **72**(4): 132-149.

Ankit., Khanna, M., Dass, A., Sudhishri, S., Babu, S., Kaur, R., Shekhawat, Prajapati, V. K., Sahoo, R. N., Singh, T., Meena, M. C., Upadhyay, P. K. and Jain, N. (2024). Wheat (*Triticum aestivum*) response under soil moisture and crop water stress

based irrigation scheduling at variable nitrogen regimes. *The Indian Journal of Agricultural Sciences*, **94**(11): 1171-1176.

Anonymous, (2024). Agricultural statistics at a glance (2023). Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

Asthir, B., Thapar, R., Farooq, M. and Bains, N. S. (2013). Exogenous application of thiourea improves the performance of late-sown wheat by inducing terminal heat resistance. *International Journal of Agriculture and Biology*, **15**(6): 1337-1342.

Barla, S. and Upasani, R. R. (2020). Performance of wheat varieties under different irrigation condition. *Journal of Pharmacognosy and Phytochem*istry, **SP5**: 205-207.

Bassiouny, H. M. E., Mostafa, H. A., El-Khawas, S. A., Hassanein, R. A., Khalil, S. I. and El-Monem, A. A. A. (2008). Physiological responses of wheat plant to foliar treatments with arginine or putrescine. *Australian Journal of Basic and Applied Sciences*, **2**(4): 1390-1403.

Bharati, S., Kant, R., Sharma, V. and Choudhary, V. (2018). Study of effect of plant growth regulating hormones for mitigating heat stress in wheat. *Current Journal of Applied Science and Technology*, **31**(2): 1-11.

Bhatt, R., Gill, R. K., Tiwari, H., Garg, A., and De Oliveira, M. W. (2025). Impacts and mitigation strategies of terminal heat stress in wheat: A Systematic Review. *International Journal of Plant and Soil Science*, **37**(11): 314-331.

Chaudhary, A. N., Patel, A. M., Mor, V. B. and Chaudhary, H. N. (2021). Effect of irrigation level and weed management practices on wheat growth, yield and economics. *Indian Journal of Weed Science*, **54**(1): 46-50.

Choudhary, R. N., Suthar, K. J. and Mahariya, V. D. (2023). Growth, yield and yield attributes of wheat (*Triticum aestivum* L.) as affected by seaweed extract under restricted irrigation condition of Bhal region, Gujarat. *The Pharma Innovation Journal,* **12**(2): 1503-1506.

Dar, E. A., Brar, A. S., Poonia, T. and Bhat, M. A. (2019). Influence of sowing dates and irrigation schedules on growth and yield of drip irrigated wheat (*Triticum aestivum*) under semi-arid conditions of Punjab. *Indian Journal of Agronomy*, **64**(2): 218-225.

Das, B., Kumar, S., Kasala, K., Nedumaran, S., Paithankar, P., Kumar, A., Jain, A. and

Avinandan, V. (2025). Effects of climate change on food security and nutrition in India: A systematic review. *Current Research in Environmental Sustainability*, **9**: 100286.

Delfine, S., Tognetti, R., Desiderio, E. and Alvino, A. (2005). Effect of foliar application of N and humic acids on growth and yield of durum wheat. *Journal of Agronomy for Sustainable Development*, **25**(2): 183-191.

Fiorentino, N., Ventorino, V., Woo, S. L., Pepe, O., De Rosa, A., Gioia, L., Romano, I., Lombardi, N., Napolitano, M. and Colla, G. (2018). *Trichoderma*-based biostimulants modulate rhizosphere microbial populations and improve N uptake efficiency, yield, and nutritional quality of leafy vegetables. *Frontiers in Plant Science,* **9**: 743.

Firdous, H. (2025). Ameliorative effects of foliar thiourea on growth, yield, and antioxidant defense in wheat. *Plant Crop Letters*, **4**: 47-53.

Ganugi, P., Masoni, A., Pietramellara, G. and Benedettelli, S. (2019). A review of studies from the last twenty years on plant arbuscular mycorrhizal fungi associations and their uses for wheat crops. *Agronomy,* **9**: 840.

Ghosh, P. K., Das, A., Saxena, R., Banerjee, K., Kar, G. and Vijay, D. (2023). *Trajectory of 75 years of Indian Agriculture after Independence*, Springer Nature. Singapore, p. 790.

Giramkar, A. S., Khedkar, D. D., Mane, M. S., Ghodke, S. K., Bhalerao, B. M., and Bhoyar, A. P. (2025). Response of biostimulant application on nutrient uptake, water productivity and economic viability in wheat cultivation. *Multilogic in science,* **15**(53): 213-218.

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd Ed. John Wiley and Sons. New York, p. 639.

Gupta, A. K., Nainwal, R. C., Singh, D. and Singh, A. K. (2016). Response of irrigation scheduling on growth and yield of late sown wheat. *Progressive Research–An International Journal*, **11**: 5307-5310.

Gupta, N. and Thind, S. K. (2017). Grain yield response of drought-stressed wheat to foliar application of glycine betaine. *Indian Journal of Agricultural Research*, **51**(3): 287-291.

Gupta, S. and Gupta, N. K. (2011). Field efficacy of exogenously applied putrescine in wheat (*Triticum aestivum*) under water-stress conditions. *Indian Journal of Agricultural Sciences*, **81**(6): 516.

Gupta, S., Agarwal, V. P. and Gupta, N. K. (2012). Efficacy of putrescine and benzyladenine on photosynthesis and productivity in relation to drought tolerance in wheat (*Triticum aestivum* L.). *Physiology and Molecular Biology of Plants*, **18**(4): 331-336.

Hassan, T. U. and Bano, A. (2016). Effects of putrescine foliar spray on nutrient accumulation, physiology, and yield of wheat. *Communications in Soil Science and Plant Analysis*, **47**(8): 931-940.

Hassanein, R. A., El-Khawas, S. A., Ibrahim, S. K., El-Bassiouny, H. M., Mostafa, H. A. and Abdel-Monem, A. A. (2013). Improving the thermo tolerance of wheat plant by foliar application of arginine or putrescine. *Pakistan Journal of Botany*, **45**(1): 111-118.

Herrera, R. M. H., Leyva, J. F. G., Hernandez, C. V. S., Alvarez, H. O., Romero, R. R. and Suarez, P. A. P. (2024). Seaweed extract ameliorates salt stress in tomato plants by enhancing the antioxidant system and expression of stress-responsive genes. *Journal of applied phycology,* **36**: 2269–2282.

Hussein, H. A. A., Alshammari, S. O., Abd El-Sadek, M. E., Kenawy, S. K. and Badawy, A. A. (2023). The promotive effect of putrescine on growth, biochemical constituents, and yield of wheat (*Triticum aestivum* L.) plants under water stress. *Agriculture*, **13**(3): 587.

Ibrahim, M. E. D., Hussein, A., Ali, A., Samak, A. and El-Koussy, A. (2023). Effect of surface irrigation systems and growth stimulants on yield and quality of wheat. *Menoufia Journal of Plant Production*, **8**(8): 171-186.

Islam, M. Z., Salim, M., Deb, B. R., Roy, S. C., Sarkar, S. K. and Paul, S. K. (2025). Enhancing wheat yield through strategic irrigation management. *Archives of Agriculture and Environmental Science*, **10**(1): 120-125.

Jackson, M. L. (1967). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, p. 498.

Kanwal, T., Maryam, H., Ahmad, R., Ahmad, S., Ali, A., Hussain, B. and Tasleem, M. W. (2020). Effect of irrigation regimes on growth and yield of wheat (*Triticum aestivum* L.) economic analysis. *International Research Journal of Advanced Science*, **1**(2): 53-59.

Karimi, Z. (2016). Putrescine foliar application effect on physiologic and morphologic characteristics of wheat (*Triticum aestivum* var. sw-82-9) under water deficit stress. *Biological Forum– An International Journal*, **8**(1): 532-539.

Kaur, G., Sreethu, S., Sharma, V. and Chhabra, V. (2025). Heat use efficiency and yield optimization in wheat as influenced by irrigation scheduling. *Journal of Agrometeorology*, **27**(4): 442-446.

Kaur, R., Kaur, S. and Sandhu, S. S. (2017). Effect of terminal heat stress in wheat and its management with chemicals in North-West India. *Agricultural Research Journal*, **54**(1): 114–116.

Kaur, R., Kumar, S., Singh, G. and Kaur, R. (2018). Effect of irrigation scheduling and mulches on growth and yield of wheat (*Triticum aestivum* L.) in Central Punjab. *International Journal of Chemical Studies*, **6**(5): 723-726.

Kumar, K., Nand, V., Pyare, R., Maurya, N. K., Niwas, R. and Singh, S. (2021). Effect of irrigation schedules on productivity of late sown varieties of wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies*, **9**(1): 3273-3277.

Kumar, P., Dheer, V., Kumar, P., Singh, J., Singh, K. K., Kumar, Y. and Singh, A. K. (2024). Effect of irrigation scheduling and different sowing dates on growth and yield of wheat (*Triticum aestivum* L.). *International Journal of Environment and Climate Change,* **14**(1): 155-161.

Lakra, K., Pyare, R., Verma, S. K., Singh, R. K., Upadhyay, P. K. and Tyagi, V. (2022). Effect of irrigation schedule and herbicides application on growth and productivity of wheat (*Triticum aestivum*) in semi-arid environment. *Indian Journal of Agronomy*, **67**(2): 129-136.

Latif, A. A., Reem, B., Injy, H. and Osman, G. (2018). Potential of *Ulva Lactuca* extract on growth, biochemical constituents, and activity of pep carboxylase of *Zea mays* seedlings. *Pakistan Journal of Botany,* **50**(5): 1971–1978.

Liu, B., Asseng, S., Müller, C., Ewert, F., Elliott, J., Lobell, D. B., Martre, P., Ruane, A. C., Wallach, D. and Jones, J. W. (2016). Similar estimates of temperature impacts on global wheat yield by three independent methods. *Nature Climate Change*, **6**: 1130-1136.

Lobell, D. B., Schlenker, W. and Costa Roberts J. (2011). Climate trends and global crop production since 1980. *Science*, **333**(6042): 616–620.

Magda, A. F., El-azeem, A. and Salem, K. (2014). Growth and productivity of barley cv Giza-129 cultivar as affected by putrescine and spermidine under water stress conditions. *Life Science Journal*, **11**(9s): 666-671.

Meena, H., Narolia, R. S., Singh, P., Meena, P. K. P. and Kumar, B. L. (2017). Effect of last irrigation scheduling and foliar spray of bio-regulators on the productivity

of wheat (*Triticum aestivum* L.) in context to the changing on climate under south east Rajasthan, India. *International Journal of Current Microbiology and Applied Sciences*, **6**(5): 1825-1830.

Meena, P. 2015. Effect of putrescine on growth and productivity of wheat (*Triticum aestivum* L.) under water stress condition. M.Sc. Thesis, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan

Nand, V., Singh, G., Kumar, R., Raj, S. and Yadav, B. (2014). Effect of irrigation levels and nutrient sources on growth and yield of wheat (*Triticum aestivum* L.). *Annals of Agriculture Research*, **35**(1): 14-20.

Nayak, M. K., Patel, H. R., Prakash, V. and Kumar, A. (2015). Influence of irrigation scheduling on crop growth, yield and quality of wheat. *Journal of Agriculture Research*, **2**(1): 65-68.

Olsen, S. R.; Cole, C. V. Watanabe, F. S. and Dean, L. A., (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate, *Circular of V. S. Department of Agriculture*, pp. 939.

Pal, A., Dwivedi, S. K. and Kanwar, P. (2015). Effect of seaweed saps on increase yield, nutrient uptake and soil nutrient balance sheet of rice. *The Ecoscan,* **9**(3): 531–535.

Pal, S., Kumar, S., Gangwar, H. K., Singh, A. and Kumar, P. (2020). Effect of scheduling irrigation based on IW/CPE ratio on dry matter accumulation, yield attributes, yield and Economics of Wheat crop (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry*, **9**(4): 1946-1949.

Pardhi, D. S., Chandan, A. S., Devi, O. R., Ashiq, I. M., Senchowa, T., Hussain, R. and Laishram, B. (2024). Effects of glycine betaine and salicylic acid foliar spray on growth of late sown wheat. *Plant Archives,* **24**(2): 2761-2768.

Patel, D., Niwas, R., Yadav, A. S., Maurya, S. K. and Kumar, J., Singh, A. (2022). Increasing productivity with profitability through irrigation scheduling and varieties of wheat (*Triticum aestivum* L.) crop. *The Pharma Innovation Journal*, **11**(7): 929-933.

Perveen, S., Farooq, R. and Shahbaz, M. (2016). Thiourea-induced metabolic changes in two mung bean [*Vigna radiata* (L.) Wilczek] (Fabaceae) varieties under salt stress. *Brazilian Journal of Botany*, **39**(1): 41-54.

Prajapat, A. L., Saxena, R., Sharma, M., Mandeewal, R. L., Lal, B. and Didal, B. (2022). Growing degree days requirement and yield of wheat cultivars as influenced by

irrigation scheduling and time of sowing. *International Journal of Plant & Soil Science*, **34**(3): 28-35.

Rossi, S. and Huang, B. (2025). Regulatory mechanisms of amino acids for improving plant tolerance to drought and heat stress–a review. *Grass Research*, **5**(1).

Rouphael, Y., Cardarelli, M., Bonini, P. and Colla, G. (2017). Synergistic action of a microbial-based biostimulant and a plant derived-protein hydrolysate enhances lettuce tolerance to alkalinity and salinity. *Frontiers in Plant Science,* **8**: 131.

Sani, M. N. H. and Yong, J. W. (2022). Harnessing synergistic biostimulatory processes: a plausible approach for enhanced crop growth and resilience in organic farming. *Biology,* **11**(1): 41.

Sarita, S., Chaudhary, S. R., Raj, M. and Kumari, V. (2021). Seaweed extract can boon the yield performances and profitability of wheat (*Triticum aestivum*). *Biological Forum – An International Journal,* **13**(3a): 459-463.

Schmidhuber J. and Tubiello F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences*, **104**(50): 19703-19708**.**

Shahbaz,M., Masood, Y., Perveen, S. and Ashraf, M., (2011). Is foliar-applied glycine betaine effective in mitigating the adverse effects of drought stress on wheat (*Triticum aestivum* L.) *Journal of Applied Botany and Food Quality*, **84**: 192 – 199.

Sharma, P., Lakra, N. and Sharma, C. (2024). Putrescine enhances heat stress tolerance in Brassica juncea L. Seedlings by modulating growth and physiological responses. *International Journal of Research in Agronomy*, **7**(8): 592-602.

Sher, A., Wang, X., Sattar, A., Ijaz, M., Allah, S. U., Nasrullah, M., Bibi, Y., Manaf, A., Fiaz, S. and Qayyum, A. (2021). Exogenous application of thiourea for improving the productivity and nutritional quality of bread wheat (*Triticum aestivum* L.). *Agronomy*, **11**(7): 1432

Shewry, P. R. and Hey, S. J. (2015). The contribution of wheat to human diet and health. *Food and Energy Security*, **4**(3): 178–202.

Singh, T., Singh, C., Kumar, R. and CV, N. (2025). Assessing the efficacy of synthetic compounds foliar sprays in alleviating terminal heat stress in late-sown wheat (*Triticum aestivum*). *Functional Plant Biology*, **52**(1): FP24184.

Singh, T., Singh, N. B., Kumar, P. and Singh, S. (2018). Effect of different irrigation and fertility levels on dynamic growth and yield of late sown wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies*, **6**(1): 1523-1528.

Sood, V., Kumar, A. and Manuja, S. (2025). Effect of biostimulants and irrigation levels on productivity of wheat (*Triticum aestivum* L.). *Himachal journal of agricultural research*, **51**(2): 263-269.

Soulé, A. M., Mansur, A. B., Mainassara, Z. A., Salami, I. and Souley, S. (2024). Effect of sowing date and irrigation frequency on wheat (*Triticum aestivum* L.) production in southern Niger Republic. *Journal of Agriculture and Ecology Research International*, **25**(4): 12-20.

Srivastava, A. K., Srivastava, S., Penna, S., and D'Souza, S. F. (2011). Thiourea orchestrates regulation of redox state and antioxidant responses to reduce the NaCl-induced oxidative damage in Indian mustard [*Brassica juncea* (L.) Czern.]. *Plant physiology and biochemistry*, **49**(6): 676-686.

Subbiah, B. V. and Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science,* **25**: 259-260.

Tanmayi, C. S. N., Biswas, R., Reddy, M. S. L., Bindu, V. K. and Mitra, B. (2024). Influence of seed treatment and foliar spraying of seaweed extracts on wheat (*Triticum aestivum* L.) in Terai region of West Bengal. *Journal of Cereal Research*, **16**(3): 2582-2675.

Tripathi, A., Gupta, S., Singh, A. K., Mishra, H. and Tripathi, S. (2023). Effect of irrigation scheduling and hydrogel level on growth and yield of wheat (*Triticum aestivum* L.). *The Pharma Innovation Journal*, **12**(6): 4934-4937.

Vafa, Z. N., Sohrabi, Y., Mirzaghaderi, G., Heidari, G., Rizwan, M. and Sayyed, R. Z. (2024). Effect of bio-fertilizers and seaweed extract on growth and yield of wheat (*Triticum aestivum* L.) under different irrigation regimes: two-year field study. *Chemosphere*, **364**: 143068.

Verma, H. P., Sharma, O. P., Kumar, R., Shivran, A. C., Sammauria, R. and Dudwal, B. L. (2018). Quality and yield of wheat (*Triticum aestivum*) as influenced by irrigation scheduling and organic manures. *Indian Journal of Agronomy*, **63**(2): 181-185.

Verma, H. P., Sharma, O. P., Yadav, L. R., Yadav, S. S., Shivran, A. C. and Kumar, R. (2018). Growth indices and yield of wheat (*Triticum aestivum* L.) as influenced by irrigation scheduling and organic manures. *Journal of Pharmacognosy and Phytochemistry*, **7**(1): 908-912.

Wahid, A., Basra, S. and Farooq, M. (2017). Thiourea: A Molecule with Immense Biological Significance for Plants. *International journal of agriculture &*

biology, **19**(4): 911-920.

Wakchaure, G. C., Minhas, P. S., Ratnakumar, P., and Choudhary, R. L. (2016). Optimising supplemental irrigation for wheat (*Triticum aestivum* L.) and the impact of plant bio-regulators in a semi-arid region of Deccan Plateau in India. *Agricultural Water Management*, **172**: 9-17.

Wang, Y., Liu, S., Zhang, H., Zhao, Y., Zhao, H. and Liu, H. (2014). Glycine betaine application in grain filling wheat plants alleviates heat and high light-induced photoinhibition by enhancing the psbA transcription and stomatal conductance. *Acta physiologiae plantarum*, **36**(8): 2195-2202.

Wasaya, A., Rehman, I., Din, A. M. U., Khalid, M. H. B., Yasir, T. A., Javaid, M. M., Hefnawy, M. E., Brestic, M., Rahman, M. A. and Sabagh, A. E. (2023). Foliar application of putrescine alleviates terminal drought stress by modulating water status, membrane stability, and yield-related traits in wheat (*Triticum aestivum* L.). *Frontiers in Plant Science*, **13**: 1000877.

Woo, S. L., Ruocco, M., Vinale, F., Nigro, M., Marra, R., Lombardi, N., Pascale, A., Lanzuise, S., Manganiello, G. and Lorito, M. (2014). *Trichoderma*-based products and their widespread use in agriculture. *The Open Mycology Journal*, **8**: 71–126.

Yadav, R. K., Kumar, M., Kumar, S. P., Singh, A. K., Singh A. K., Kumar, B., Pandey, A. K. and Singh, A. (2021). Effect of foliar application of different nutrients on growth and yield of wheat (*Triticum aestivum* L.) in an under sodic soil. *The Pharma Innovation Journal*, **10**(1): 589-594.

Yaseen M., Ahmed, W., Arshad, M. and Ali, Q. (2011). Response of wheat to foliar feeding of micronutrients. *International Journal for Agro Veterinary and Medical Sciences*, **5**(2): 209-220.

Zain, M., khan, I., Chattha, M. U., Qadri, R. W. K., Anjum, S. A., Hassan, M. U., Mahmood, A. and Ilyas, M. (2017). Foliar applied thiourea at different growth stages modulated late sown wheat. *Pakistan Journal of Science*, **69**(1): 305-309.

Zhao, K., Tao, Y., Liu, M., Yang, D., Zhu, M., Ding, J., Zhu, X., Guo, W., Zhou, G. and Li, C. (2022). Does temporary heat stress or low temperature stress similarly affect yield, starch, and protein of winter wheat grain during grain filling. *Journal of Cereal Science*, **103**: 103408

Zhao, W., Liu, L., Shen, Q., Yang, J., Han, X., Tian, F. and Wu, J. (2020). Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. *Water*, **12**(8): 21

Signature of Student **Signature of Major Guide**

(Piyush Patel) **(G. S. Vala)**